Overview

- **Some project highlights**
  - Fatigue life inference from dynamic measurements
  - Power transmission through connected launch vehicle panels

- **Student Research**
  - Recharacterization of the CAV reverberation room

- **Focus area: fluid-structure interaction**
  - Simulations and measurements
Fatigue Life Estimation of Composite Structures using Modal Analysis Data

Principal Investigator: K.L. Koudela
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Sponsor:
Fatigue Life Estimation

- Predict residual strength after fully-reversed fatigue cycling using coupon data, modal analyses and static failure load
- Conduct fully-reversed fatigue testing (two blades) at $\pm 13.7$ ksi to 100,000 cycles
- Perform intermittent modal analysis to measure stiffness reduction
- Conduct residual strength static-tests-to-failure
Measured natural frequency reduction of 5% corresponds to stiffness decrease of 10%.
Fatigue Life Estimation

Predicted residual strengths of 5906 lbs within 4% of measured residual strengths of 5886 and 5694 lb
Structure-borne power through joints between composite and metal structures

Advisors: S.A. Hambric and S.C. Conlon

Researchers: Ben Grisso (Ph.D. Post-Doctoral Student)
Andrew Barnard (PhD Student)
Micah Shepherd (PhD Student)

Sponsor: United Launch Alliance
Test Setup

Panel 2

Panel 1

9 May 2011
Sleeve Joints
Wavenumber transform-based transmission coefficients
Coupling loss factors from transmission coefficients and E-SEA
Re-characterization of the CAV Reverberant Room

Advisor: S.A. Hambric

Researcher: Andrew Orr (M.S. Acoustics pending)
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CAV Reverberation Room

- Update room characterization using modern methods and standards
  - Use roving omnidirectional sound source and microphones
  - T60 ringdown times
  - Absorption coefficients
  - Spatial variability
  - Low-frequency modes
Microphones(2): ½” phase matched Tef Goldline omnidirectional condensers

Other equipment: Crown Power Amp, Fluke multimeter, HP signal generator

Not pictured: Renkus-Heinz EASERA Gateway

Source: B&K 4292
T60 ringdown times

All various reverberation times calculated for empty chamber

Comparison of reverb times

Sample Decay in 100 Hz third octave band
Modal Loss Factors

\[ f = 26.0 \text{[Hz]} \]
\[ \eta = 0.0206 \]
\[ T_{60} = 4.1 \text{ s} \]

\[ f = 40.4 \text{[Hz]} \]
\[ \eta = 0.0221 \]
\[ T_{60} = 2.5 \text{ s} \]

\[ f = 175.7 \text{[Hz]} \]
\[ \eta = 0.0085 \]
\[ T_{60} = 1.5 \text{ s} \]

\[ T_{60} = \frac{2.2}{f \eta} \]
Modal Loss Factors vs T60 data

Comparison of reverb times

- Balloon Pops
- Source
- Modal Analysis

Frequency (Hz)

Reverb Time (s)
Next Steps

• Textbook values for room absorption coefficients (walls, floor, ceiling) don’t appear correct
  – Attempt to infer bare room absorption coefficients by measuring increasing in overall absorption when adding absorbing material

• Reduce spatial pressure variability
  – add hanging diffusers, remeasure variability and establish compliance with required standard
Focus Area: Fluid-Structure Interaction

Principal Investigator: R.L. Campbell
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Sponsors: US Navy, ARL/Penn State, DARPA, and others
Goals

- **Simulations:**
  - High-fidelity, *fully coupled* simulations of unsteady fluid-structure interaction phenomena: hydrofoil singing, human speech, blood vessels and implants, heat exchanger tube bundle vibration, etc.

- **Measurements:**
  - Simultaneous measurement of full spatial-temporal evolution of both the fluid and structure for prototype and/or full-scale assessment and simulation tool validation

- **Examples (lifting foils):**
  - Flexible strut (from RLC thesis)
  - Unsteady multi-phase flow sample
  - Singing strut (from MCR thesis)
Simulation Procedures

- **Simulation procedure summary**
  - Goal: *monolithic solver* - both fluid and solid domains cast in terms of same primitive variables (velocity and stress) and system of equations solved simultaneously
  - Current: *partitioned solver* – existing flow and structure solvers stitched together with sub-iterations to ensure tight convergence
    - OpenFOAM (open source CFD software) for the fluid modeling
    - feanl (author-developed nonlinear finite element solver) for structure modeling
    - Fluid mesh motion required to accommodate structural deformation: several techniques available, including author-developed technique, chosen at run-time
    - Solver is parallelized (a requirement!)
Example: Unsteady FSI Simulation

- Unsteady (and multi-phase) FSI simulation example using same solver framework described above
- Water held by thin membrane; membrane removed at t=0^+

![Diagram of unsteady FSI simulation with water, air, membrane, and gravity](image)

- Air
- Membrane – removed at start of simulation
- Water
- Flexible Structure
- Gravity
DamBreak with Flexible Strut

Fluid Phase Fraction

0
0.25
0.5
0.75
1

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Example: Flexible Strut

- **Objective:** validate FSI solver for simulation of collapsible blood pump.
Measurement Procedures

- **Measurements procedure summary**
  - High-speed Stereo Particle Image Velocimetry (PIV) to measure surface velocity and acceleration: uses a combination of high-speed LED lamps and cameras to track markers on the structure’s surface.
  - High-speed Shadow PIV to simultaneously measure surface deflection and flow motion: an image of shadows of particles in the flow, and bright scattering markers on the solid surface are illuminated by the same LED lamps.
  - Unsteady Surface Force measurement using Surface Shear Stress Films (S3F): deformations of the surface film are measured optically, and converted to surface shear and normal stresses.
  - Load cells for reaction force and moment characterization.
Water Tunnel and Data Acquisition

- 12-inch water tunnel facility at ARL
- Instrumented with pressure sensors (to estimate flow speed), temperature sensors, and video camera (fin deformation)
Water Tunnel Test Section (While Filling)
Tightly-coupled FSI simulations using partitioned solver
- OpenFOAM flow solver, in-house nonlinear FE structural solver, and custom dynamic mesh for fluid mesh motion
- Supports disparate fluid/solid interface meshes
- Solver compiled and built as single executable
  • Efficient interface communication via RAM

Example – NACA 66 soft polymer hydrofoil deformation time histories
Example: Singing Strut

- Measurements of NACA 66 hydrofoil loss factors at various flow rates
  - Shed vortices lock-in to structural modes at specific flow speeds
  - Oscillating lift damps vibrations at higher flow speeds
  - Quantified behavior for several mode types, flow speeds, and angles of attack

![Diagram showing flow visualization and data points](image)
Future Projects

- Development of Acoustically Tailored Composite Rotorcraft Fuselage Panels
  - Joint with Bell Helicopter and Kansas State University
  - Combine treatments:
    - Embedded viscoelastomers
    - Band-gap systems
    - Tailored composites
Future Projects – Martin Guitars

Radiated sound power transfer functions